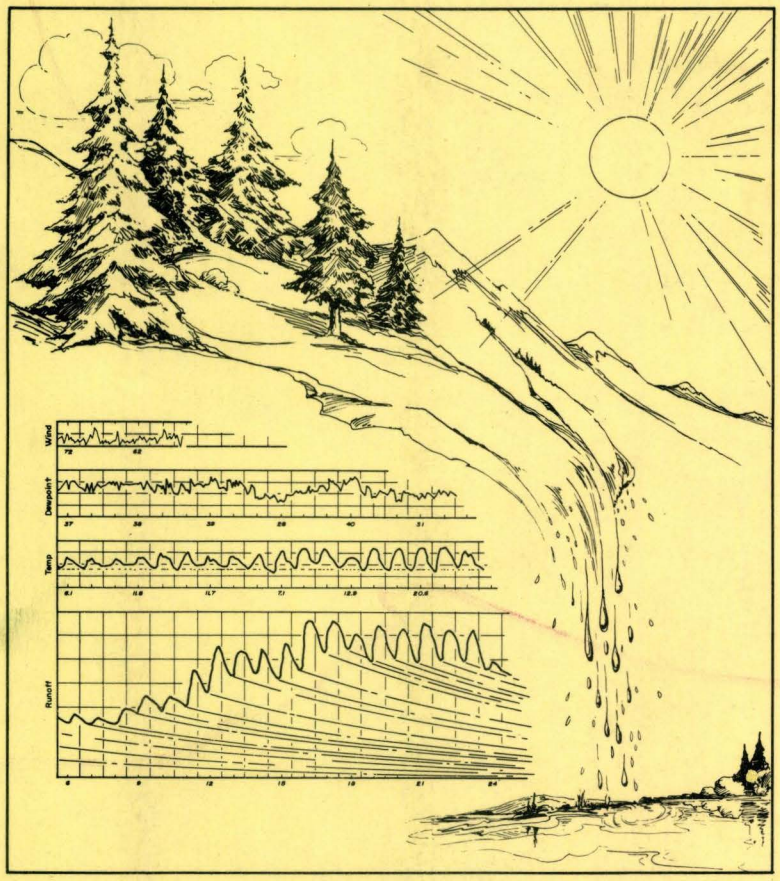
COOPERATIVE SNOW INVESTIGATIONS

DEPARTMENT OF AGRICULTURE
FOREST SERVICE
ROCKY MOUNTAIN FOREST AND
RANGE EXPERIMENT STATION

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROJECT PLANNING DIVISION
HYDROLOGY BRANCH

PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST COLORADO



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THE 1950 SNOWMELT SEASON

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THE 1950 SNOWMELT SEASON

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PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST

THE 1950 SNOWMELT SEASON

INTRODUCTION.

This is the third progress report on cooperative snow investigations being conducted by the Bureau of Reclamation and the Forest Service at the Fraser Experimental Forest near Fraser, Colorado, under the general direction of Mr. J. R. Riter, Chief, Hydrology Branch, Project Planning Division, Bureau of Reclamation, United States Department of the Interior, Denver, Colorado; and Dr. W. G. McGinnies, Director, Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Fort Collins, Colorado. A detailed description of the Fraser Experimental Forest is given in Report No. 1, The 1948 Snowmelt Season (1).[1/] A map of the St. Louis Creek drainage basin is shown on the frontispiece of Report No. 2, The 1949 Snowmelt Season (2). The Bureau of Reclamation's interest in this cooperative investigation stemmed from the desire for improving the accuracy of both seasonal water yield and rate-of-run-off forecasts for use in the planning and operation of Reclamation projects, and from the need for more precise information about rates of run-off from snowmelt for use in flood design studies and computations as set forth in Report No. 1.

This progress report covers four of the five subprojects reported in Report No. 1, as viewed in the light of newer methods of analysis applied to the data from the 1948, 1949, and 1950 snowmelt seasons. Computations and analyses completed for the 1950 and the combined 1948, 1949, and 1950 seasons are summarized but the tabulations of basic data are not included in this report.

OBSERVATIONS OF THE PERFORMANCE OF SACRAMENTO-TYPE SHIELDED PRECIPITATION STORAGE GAGES.

The performance of the Weather Bureau Design, Sacramento-type shielded seasonal-storage precipitation gages during the 1950 season is summarized in Figure 1. Table 1 of Report No. 2 presents a similar summary for the years 1947 to 1949. In Report No. 1 there is a detailed discussion with several photographs of the storage gage installations and their performance in the Fraser Experimental Forest.

[1/] Numbers in parentheses refer to "References," page 22.

SUMMARY OF SEASONAL STORAGE PRECIPITATION GAGES, 1950

1950	Station Elevation (ft) Capacity (inch) Shield	East St. Louis Creek 9,520 100 Shielded		Iron Creek 9,680 100 Shielded		Range Creek 9,360 100 Shielded		St. Louis Pass 10,330 200 Unshielded		West St. Louis Creek 9,840 100 Shielded		West St. Louis Creek 9,840 100 Unshielded	
Nominal date of survey		Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)
April 1	Gage increment	8-30-49 to 3-31-50	16.2	9-2-49 to 3-30-50	12.8	9-1-49 to 3-30-50	8.4	9-12-49 to 3-30-50	14.6	9-13-49 to 3-29-50	17.3	9-13-49 to 3-29-50	14.3
	Snow survey	3-31-50	15.9	3-30-50	12.55	3-30-50	12.35	3-30-50	19.92	3-29-50	21.6	3-29-50	21.6
May 1	Gage increment	3-31-50 to 5-1-50	3.3	3-30-50 to 4-28-50	3.9	3-30-50 to 4-28-50	2.5	3-30-50 to 4-28-50	5.6	3-29-50 to 5-2-50	5.15	3-29-50 to 5-2-50	4.25
	Snow survey	5-1-50	15.6	4-28-50	9.4	4-28-50	13.3	4-28-50	22.6	5-2-50	20.8	5-2-50	20.8

TABLE 1. Summary of seasonal storage precipitation gages, 1950.

ANALYSIS OF RATES OF SNOWMELT.

St. Louis Creek

The periods of record chosen for analysis of run-off in St. Louis Creek are: May 14-16, May 19-24, and May 27-June 5, 1948; May 23-27, June 1-10, and June 15-25, 1949; and May 13-June 28, 1950. Days other than those listed above were not used because all data needed for certain analyses were not available. For the 1950 season, as many days as possible were used for each set of correlation equations, hence the various values of N appearing in Tables 3 and 4. All available run-off records were used in the analyses shown in Figures 12, 13, 14, 15, and 16 of Report No. 2, The 1949 Snowmelt Season (2) and their counterparts in this report, Figures 4, 5, 6, 7, 8, and 9 and described in the Section of this report entitled: "Synthesis of the Snowmelt Hydrograph." The 1950 St. Louis Creek hydrograph for April 1 to September 30, inclusive, is shown in Figure 1. Similar hydrographs of St. Louis Creek, together with precipitation observed at the town of Fraser, Colorado, are available for the period of record of run-off beginning with 1935.

One day's average flow in cfs of St. Louis Creek was plotted against the preceding day's average flow using only the falling stages of days uninfluenced by rainfall for the 1947 and 1948 snowmelt seasons to determine a recession factor. For this period, the daily recession factors as computed from that plotting were found to be 0.933 for stages above about 30 cfs and 0.981 for stages below about 30 cfs. A chart showing this relationship was presented as Figure 6 in Report No. 2. These recession values were found to fit the hydrographs of St. Louis Creek for the period 1935 to 1948, inclusive. Figure 2 shows the plotting of 1949 and 1950 data with the lines derived from 1947 and 1948 points drawn in. The daily recession values as based on 1947 and 1948 data also fit the 1949 and 1950 data.

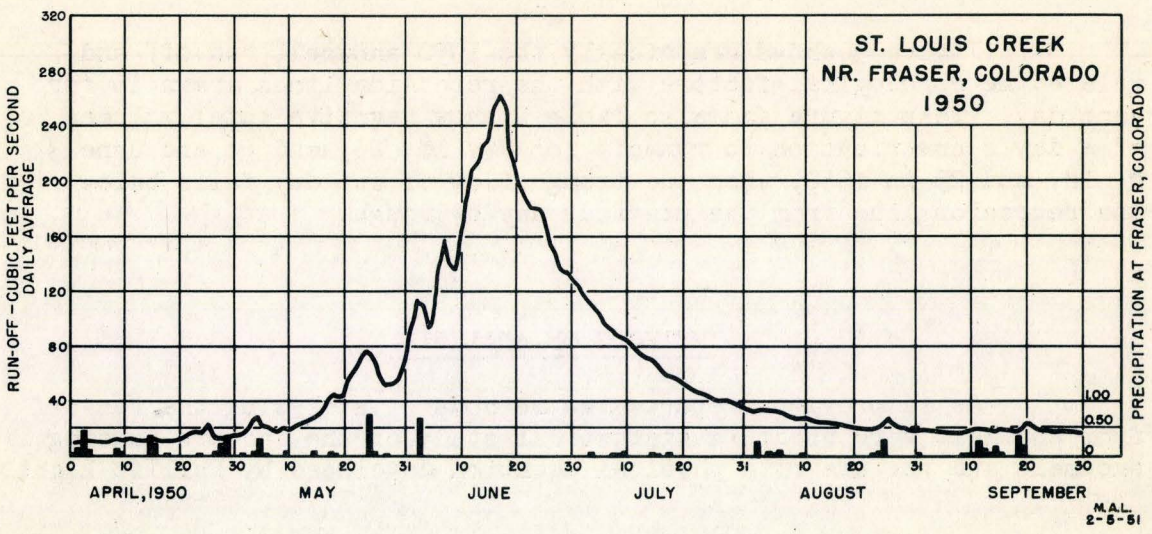


FIGURE 1. Hydrograph of St. Louis Creek, 1950.

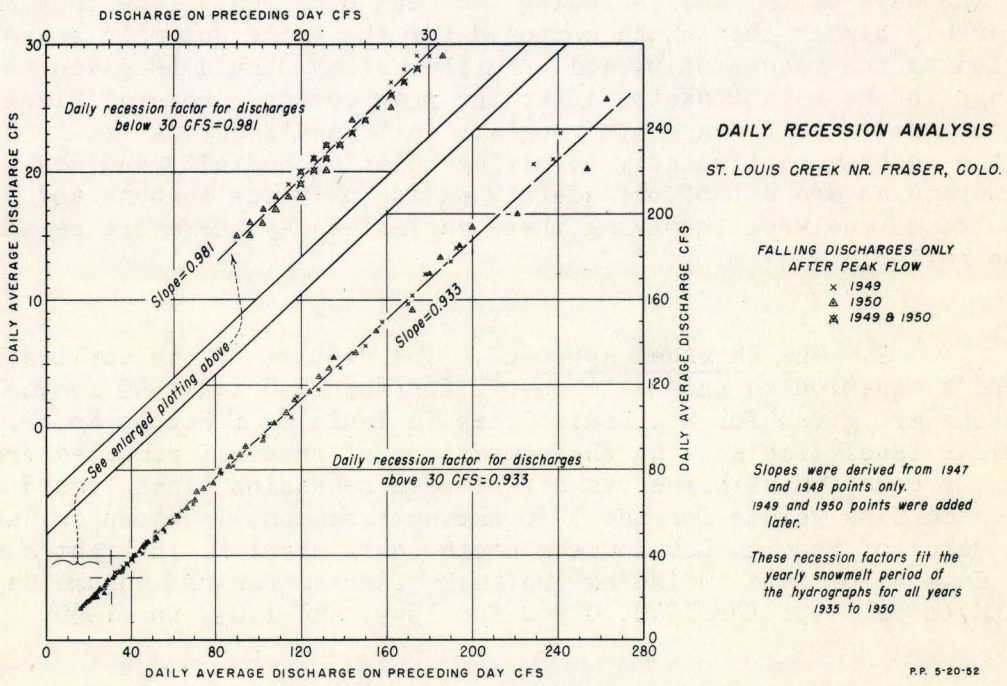

DISCHARGE ON PRECEDING DAY CFS
DAILY AVERAGE DISCHARGE CFS
Daily recession factor for discharges below 30 CFS=0.981
Slope=0.981
See enlarged plotting above
Slope=0.933
Daily recession factor for discharges above 30 CFS=0.933
DAILY AVERAGE DISCHARGE ON PRECEDING DAY CFS
DAILY RECESSION ANALYSIS
ST. LOUIS CREEK NR. FRASER, COLO.
FALLING DISCHARGES ONLY
AFTER PEAK FLOW
× 1949
△ 1950
⊠ 1949 & 1950
Slopes were derived from 1947 and 1948 points only.
1949 and 1950 points were added later.
These recession factors fit the yearly snowmelt period of the hydrographs for all years 1935 to 1950
P.P. 5-20-52

FIGURE 2. St. Louis Creek recession, 1949 and 1950.

Figure 3 shows graphically the 1950 snowmelt run-off and related meteorological factors with the recession lines drawn in for each day. This figure and also Table 2 show negative total volumes of a day's contribution to run-off for May 18, 25, and 26 and June 3, 8, 18, and 25 in 1950, when the trough flow of one day falls below the recession line from the previous day's trough.

METHODS OF ANALYSIS

As in previous reports two methods of analyzing the run-off from snowmelt were used: a statistical study of the factors causing snowmelt and the use of a physical equation developed by Phillip Light.

1. The Statistical Approach. Multiple correlation analyses were computed relating the run-off to the various factors causing snowmelt using the same variables as Equations 6 and 6A from Report No. 2 for the 1950 data and for the combined 1948, 1949, and 1950 data. Simple correlations corresponding to Equations 32, 32A, 33, and 33A from Report No. 2 were also computed for the 1950 season and the combined 1948, 1949, and 1950 seasons both for the entire period and the period up to and including the observed peak volume day. Results of these correlation analyses are shown in Tables 3 and 4.

As indicated in these tables, correlation coefficients computed for the days before and including the peak observed volume only are considerably higher than those computed for the whole snowmelt season including the recession period. Further study should be given to the change in the relationships after the peak occurs. Some difficulty was encountered with the hygrothermograph instruments during the 1950 season so the records particularly involving relative humidity and dew point temperatures are not of the quality as for previous seasons and the results of analyses involving these variables may therefore be somewhat less reliable.

2. The Physical Approach. The results of the application of Light's equation to snowmelt run-off for the 1948 and 1949 snowmelt seasons are given for St. Louis Creek in Table 8 of Report No. 2. A similar tabulation showing the comparison of snowmelt computed from Light's equation with the run-off between recession lines, based on recorded flow volume for the 1950 snowmelt season, is shown in Table 5. The value of the St. Louis Creek basin coefficient K, in Light's equation, for days before and including the peak observed run-off volume day, was found to be 0.951 for 1948, 0.960 for 1949, and 1.037 for 1950.

SOLAR RADIATION UPON HORIZONTAL SURFACE AT SHADOW MOUNTAIN SNOW COURSE, GRAND LAKE, COLO.

GRAM CALORIES PER HOUR PER SQUARE CENTIMETER FOR HOUR ENDING

MAY 1950 — JUNE 1950

12 mdnt. 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

514 658 648 419 608 638 359 796 843 774 748 709 403 140 618 469 315 679 754 790 835 616 349 715 820 760 760 820 849 844 825 844 792 857 797 744 846 808 534 735 551 521 796 708 821 708 616 552 728

Gram-calories per square centimeter- total for the day.

WIND AT 47.4 FOOT LEVEL ON TOWER NEAR WEST ST. LOUIS CREEK

MILES FOR HOUR ENDING

115 93 96 104 83 73 93 138 111 123 129 98 49 103 124 118 134 138 128 118 69 116 129 142 119 103 124 123 135 133 131 132 123 134 120 103 97 117 104 103 113 131 99 121 100 116

Miles of wind- total for the day.

DEWPOINT TEMPERATURE AT HEADQUARTERS STATION

DEGREES FAHRENHEIT

23 26 27 33 28 28 30 16 15 23 26 27 33 25 24 28 24 28 23 20 26 30 26 29 23 18 16 19 29 25 27 25 32 42 26 22 30 31 32 29 30 29 27 29 35 32 34

Average dewpoint temperature for the day.

AIR TEMPERATURE AT HEADQUARTERS STATION

DEGREES FAHRENHEIT

7.8 7.9 11.5 8.0 10.3 13.2 6.6 8.2 7.7 12.5 16.2 15.4 10.0 0.4 7.0 8.2 8.0 15.5 13.2 16.5 13.9 1.1 7.0 15.5 22.1 16.0 8.2 12.9 20.5 21.4 21.8 22.2 24.4 24.2 23.3 19.8 19.7 16.4 17.5 17.6 23.0 23.2 21.0 22.5 21.5 22.3 19.2

Degree days above 32°F. computed from thermograph trace.

RUNOFF RECORDED AT U.S. GEOLOGICAL SURVEY GAGING STATION AT ST. LOUIS CREEK NEAR FRASER, COLORADO

CUBIC FEET PER SECOND

12 mdnt. 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

MAY 1950 — JUNE 1950

186.1 305.3 44.3 305.1 273.5 -61.8 95.2 179.4 377.1 337.2 329.3 21.7 -34.3 -150.0 17.9 93.0 86.7 489.6 535.4 636.7 520.8 -365.7 176.2 574.3 975.5 410.9 -113.7 611.2 931.2 867.0 542.7 698.4 609.2 1275.6 1084.8 216.6 -391.3 154.8 207.9 164.4 67.6 203.7 133.1 -31.0 81.9 144.6 252.7

Acre-feet Total contribution to run-off of the day's snowmelt as computed from recession curve analysis of recorded hydrograph.

RUNOFF (continued)

CUBIC FEET PER SECOND

30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8

JULY 1950 — AUG. 1950

COOPERATIVE SNOW INVESTIGATIONS

UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION PROJECT PLANNING DIVISION HYDROLOGY BRANCH

1950 SNOWMELT RUNOFF AND RELATED METEOROLOGICAL FACTORS

ST. LOUIS CREEK
AREA 32.8 SQUARE MILES

FRASER EXPERIMENTAL FOREST, COLORADO

JULY 15, 1952

FIGURE 3
5

RUN-OFF VOLUMES

ST. LOUIS CREEK

1950

Date 1950	Trough 1/ cfs	Peak 2/ cfs	Total first day volume 3/ acre-feet	Net first day volume above recession 4/ acre-feet	Total run-off between recession lines 5/ acre-feet	Date 1950	Trough 1/ cfs	Peak 2/ cfs	Total first day volume 3/ acre-feet	Net first day volume above recession 4/ acre-feet	Total run-off between recession lines 5/ acre-feet
May 13	22	30	55	9	186	June 6	100	172	284	93	976
14	24	35	61	12	305	7	126	191	308	67	411
15	28	35	59	7	44	8	131	138	255	5	-114
16	28	42	73	18	305	9	117	162	273	48	611
17	34	59	102	34	273	10	131	218	355	104	931
18	42	44	80	-2	-62	11	152	239	406	114	867
19	37	51	86	15	95	12	170	251	422	96	543
20	38	58	93	23	179	13	175	260	441	105	698
21	42	74	126	42	377	14	185	266	460	106	609
22	54	87	145	42	337	15	191	263	464	113	1276
23	62	92	156	37	329	16	221	284	521	97	1085
24	70	86	151	18	22	17	242	296	565	64	217
25	65	68	126	1	-34	18	230	269	450	27	-391
26	59	55	105	-8	-150	19	200	239	418	34	155
27	49	55	92	5	18	20	191	215	388	22	208
28	47	61	109	16	93	21	185	209	385	30	164
29	47	54	103	10	87	22	178	191	356	16	68
30	47	79	134	44	490	23	168	191	355	35	204
31	62	102	169	50	535	24	162	191	352	41	133
June 1	77	126	210	62	637	25	155	182	323	26	-31
2	94	135	236	56	521	26	142	168	300	27	82
3	105	96	171	-15	-366	27	135	150	279	20	145
4	86	96	193	16	176	28	131	142	268	18	253
5	86	126	218	54	574	29	131				

Footnote numbers in Table 2 refer to points designated on Figure 7, Report No. 2, p. 8.

1/ Trough is Point T.
2/ Peak is Point B.
3/ Total area under hydrograph for the day and above a zero base line.
4/ Net first day volume is Area 1.
5/ Total run-off volume is Area 1 plus Area 2.

TABLE 2. Run-off volumes, St. Louis Creek, 1950.

SUMMARY OF CORRELATIONS--1950
ST. LOUIS CREEK, COLORADO

Equation number	Dependent variable	Independent variables X_2	X_6	X_7	X_{11}	a	$\bar{R}$	N
6	$X_{1.267}$	2.202	0.881	0.717		-13.40	0.49	43
6A	$X_{1A.267}$	2.705	0.397	0.703		-10.34	0.72	43
32	$X_{1.11}$				1.734	- 8.24	0.55	47
32A	$X_{1A.11}$				2.214	-10.40	0.72	47
33	$X_{1.2}$	2.435				- 0.62	0.43	43
33A	$X_{1A.2}$	3.470				- 1.31	0.66	43
(DAYS BEFORE AND INCLUDING PEAK VOLUME ONLY)								
32	$X_{1.11}$				2.712	-13.19	0.87	34
32A	$X_{1A.11}$				3.043	-14.58	0.91	34
33	$X_{1.2}$	5.001				- 2.77	0.88	30
33A	$X_{1A.2}$	5.822				- 3.31	0.95	30

LIST OF VARIABLES USED IN CORRELATION ANALYSIS OF DAILY SNOWMELT

Identification	Description of variable	Units
X_1	Total run-off from 1 day's contribution to the hydrograph	100 acre-feet
X_{1A}	First day run-off volume above recession	10 acre-feet
X_2	Degree-days above 32° F at Headquarters	10° days
X_6	Relative humidity at Headquarters	10 percent
X_7	Daily wind travel at 47.4 feet in open	10 mile
X_{11}	Maximum temperature at Headquarters	10° F

TABLE 3. Summary of correlations, 1950.

SUMMARY OF CORRELATIONS--1948, 1949, and 1950
ST. LOUIS CREEK, COLORADO

Equation number	Dependent variable	Independent variables X_2	X_6	X_7	X_{11}	a	$\bar{R}$	N
6	$X_{1.267}$	2.515	0.675	0.533		-10.20	0.53	88
6A	$X_{1A.267}$	3.567	0.626	0.526		-10.58	0.73	88
32	$X_{1.11}$				1.704	- 7.44	0.52	92
32A	$X_{1A.11}$				2.303	-10.40	0.71	92
33	$X_{1.2}$	2.782				- 0.63	0.49	88
33A	$X_{1A.2}$	3.893				- 1.47	0.70	88
(DAYS BEFORE AND INCLUDING PEAK VOLUME ONLY)								
32	$X_{1.11}$				2.595	-12.07	0.78	66
32A	$X_{1A.11}$				2.920	-13.78	0.85	66
33	$X_{1.2}$	5.014				- 2.65	0.85	62
33A	$X_{1A.2}$	5.513				- 3.11	0.90	62

LIST OF VARIABLES USED IN CORRELATION ANALYSIS OF DAILY SNOWMELT

Identification	Description of variable	Units
X_1	Total run-off from 1 day's contribution to the hydrograph	100 acre-feet
X_{1A}	First day run-off volume above recession	10 acre-feet
X_2	Degree days above 32° F at Headquarters	10° days
X_6	Relative humidity at Headquarters	10 percent
X_7	Daily wind travel at 47.4 feet in open	10 mile
X_{11}	Maximum temperature at Headquarters	10° F

TABLE 4. Summary of correlations, 1948, 1949, and 1950.

COMPARISON OF SNOWMELT COMPUTED FROM LIGHT'S EQUATION, 1950

St. Louis Creek near Fraser, Colorado
Area = 32.8 Square Miles

Date 1950	Run-off between recession lines		Departure of computed from measured volume		Date 1950	Run-off between recession lines		Departure of computed from measured volume	
	Computed by Light's Equation	Based on recorded flow				Computed by Light's Equation	Based on recorded flow		
	inch	inch	inch	%		inch	inch	inch	%
May 13	0.025	0.106	-0.082	-76.7	June 8	0.021	-0.065	0.086	131.8
14	0.090	0.174	-0.084	-48.4	9	0.127	0.349	-0.222	-63.6
15	0.129	0.025	0.104	411.5	10	0.396	0.532	-0.137	-25.7
18	0.088	-0.035	0.123	349.0	11	0.409	0.496	-0.086	-17.4
19	0.007	0.054	-0.048	-87.3	12	0.415	0.310	0.105	33.8
20	0.009	0.103	-0.094	-91.5	13	0.468	0.399	0.068	17.1
21	0.095	0.216	-0.120	-55.9	15	0.854	0.729	0.125	17.1
22	0.131	0.193	-0.062	-32.0	16	0.902	0.620	0.282	45.5
23	0.309	0.188	0.121	64.2	17	0.428	0.124	0.304	245.5
24	0.284	0.012	0.272	2191.1	18	0.310	-0.224	0.534	238.5
27	0.035	0.010	0.025	243.1	19	0.355	0.088	0.266	301.1
28	0.146	0.053	0.093	174.2	20	0.263	0.119	0.144	121.0
29	0.072	0.050	0.022	44.2	21	0.452	0.094	0.358	380.4
30	0.458	0.280	0.178	63.6	22	0.426	0.039	0.388	1003.9
31	0.212	0.306	-0.094	-30.6	23	0.463	0.116	0.346	297.6
June 1	0.129	0.364	-0.235	-64.5	24	0.578	0.076	0.502	659.5
4	0.018	0.101	-0.082	-81.7	25	0.344	-0.018	0.362	2044.6
5	0.298	0.328	-0.030	-9.3	26	0.470	0 047	0.423	903.8
6	0.363	0.558	-0.194	-34.9	27	0.510	0.083	0.427	516.3
7	0.265	0.235	0.030	12.8	28	0.553	0.144	0.409	283.0
					TOTAL	11.907	7.379	4.527	61.35
					Total through June 15	5.853	6.071	-0.218	-3.59

Basin Coefficient, $K = \frac{6.071}{5.853} = 1.0372$
(Through June 15, peak volume day)

Basin Coefficient, $K = \frac{7.379}{11.907} = 0.6197$
(Through June 28)

TABLE 5. Comparison of snowmelt computed from Light's equation, 1950.

EVAPORATION FROM SNOW COMPUTED BY LIGHT'S EQUATION, 1950
ST. LOUIS CREEK NEAR FRASER, COLORADO

Total inches for 24-hour period including lag time					
Date	Exclusive of periods having avg temp below 32°F	Including periods of avg temp below 32°F 2/	Date	Exclusive of periods having avg temp below 32°F	Including periods of avg temp below 32°F 2/
May 13 1/	0.109	0.166	June 8 1/	0.256	0.332
14 1/	0.096	0.117	9	0.192	0.192
15	0.020	0.020	10	0.066	0.066
18 1/	0.045	0.066	11	0.107	0.107
19	0.320	0.320	12	0.124	0.124
20 1/	0.268	0.355	13	0.050	0.050
21 1/	0.109	0.142	15	0.008	0.008
22	0.138	0.138	16	None	None
23	0.084	0.084	17	0.138	0.138
24	None	None	18	0.108	0.108
27	0.170	0.170	19	0.069	0.069
28 1/	0.060	0.078	20	0.024	0.024
29	0.197	0.197	21	0.012	0.012
30	0.035	0.035	22	0.018	0.018
31 1/	0.118	0.203	23	0.021	0.021
June 1 1/	0.211	0.261	24	0.010	0.010
4 1/	0.034	0.097	25	0.162	0.162
5	0.047	0.047	26	0.006	0.006
6	0.186	0.186	27	None	None
7 1/	0.252	0.276	28	0.001	0.001
			TOTAL	3.871	4.406
			Total through June 15	3.302	3.837

1/ Days for which there is at least one 6-hour period having avg temp below 32°F.

2/ Not corrected for vapor pressure corresponding to avg temp dew point.

TABLE 6. Evaporation from snow computed by Light's equation, 1950.

CALCULATION OF EVAPORATION LOSSES FROM THE SNOW BLANKET DURING THE SNOWMELT SEASON.

The use of Light's equation to compute the evaporation from the snow surface, and the tabulations of daily totals of evaporation loss as computed for both the 1948 and 1949 seasons were presented in Table 11 of Report No. 2. A similar table for the days of record in the 1950 snowmelt period is presented in Table 6. A comparison of the computed evaporation in 1948, 1949, and 1950 follows:

Evaporation from Snow Computed by Light's Equation

Year	Total Evap* Inches	No. of Days	Evap. per Day Inches
1948	1.302	16	0.0814
1949	1.410	21	0.0671
1950	3.302	27	0.1223

*Total inches for days of record exclusive of periods having average temperature below 32° F and for days before and including peak measured volume only. The period chosen is the same as that used to determine the basin coefficient for the hydrograph synthesis.

SYNTHESIS OF THE SNOWMELT HYDROGRAPH.

St. Louis Creek

The preliminary analysis of the areas and shapes of the hydrograph as presented on page 13 of Report No. 1 and in Figure 7 of Report No. 2 were continued using data from the 1948, 1949, and 1950 seasons.

Figure 4 shows the relationship of the first day's volume and the total volume for the 1950 snowmelt season. Figure 5, the counterpart of Figure 12 in Report No. 2, shows the least squares line computed to relate the first day's volume and the total run-off using only the days before and including the day of greatest volume in 1948, 1949, and 1950 combined.

Figure 6 shows the relation between the height to the peak and the first-day volume from the 1950 data with the least squares line computed from 1948 and 1949 data drawn in for comparison purposes. Visual examination would indicate that the same line would very nearly fit the 1950 data.

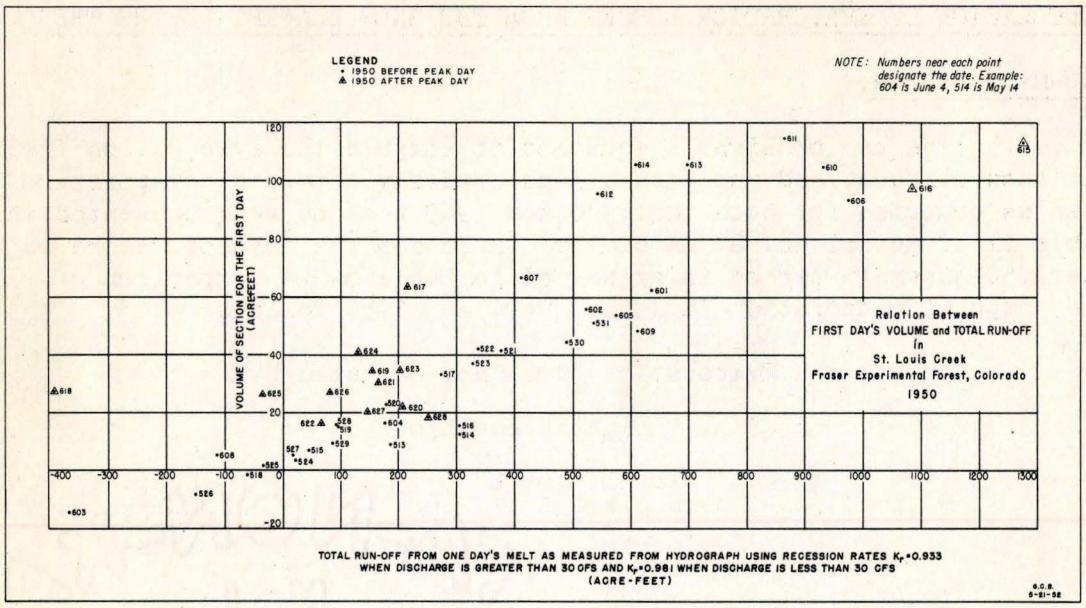

LEGEND
• 1950 BEFORE PEAK DAY
▲ 1950 AFTER PEAK DAY
NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14
VOLUME OF SECTION FOR THE FIRST DAY (ACRE FEET)
Relation Between
FIRST DAY'S VOLUME and TOTAL RUN-OFF
in
St. Louis Creek
Fraser Experimental Forest, Colorado
1950
TOTAL RUN-OFF FROM ONE DAY'S MELT AS MEASURED FROM HYDROGRAPH USING RECESSION RATES K_r = 0.933 WHEN DISCHARGE IS GREATER THAN 30 CFS AND K_r = 0.981 WHEN DISCHARGE IS LESS THAN 30 CFS (ACRE-FEET)
6-21-52

FIGURE 4. Relation between first-day volume and total run-off in St. Louis Creek, 1950.

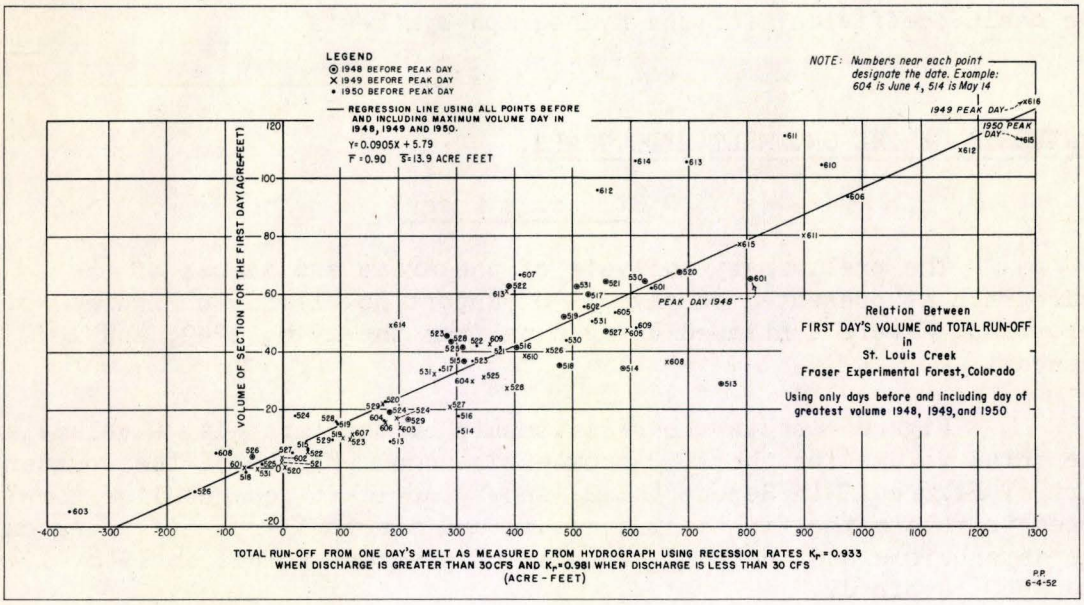

LEGEND
⊙ 1948 BEFORE PEAK DAY
× 1949 BEFORE PEAK DAY
• 1950 BEFORE PEAK DAY
— REGRESSION LINE USING ALL POINTS BEFORE AND INCLUDING MAXIMUM VOLUME DAY IN 1948, 1949 AND 1950.
Y = 0.0905X + 5.79
r = 0.90 σ = 13.9 ACRE FEET
NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14
1949 PEAK DAY
1950 PEAK DAY
PEAK DAY 1948
VOLUME OF SECTION FOR THE FIRST DAY (ACRE FEET)
Relation Between
FIRST DAY'S VOLUME and TOTAL RUN-OFF
in
St. Louis Creek
Fraser Experimental Forest, Colorado
Using only days before and including day of greatest volume 1948, 1949, and 1950
TOTAL RUN-OFF FROM ONE DAY'S MELT AS MEASURED FROM HYDROGRAPH USING RECESSION RATES K_r = 0.933 WHEN DISCHARGE IS GREATER THAN 30 CFS AND K_r = 0.981 WHEN DISCHARGE IS LESS THAN 30 CFS (ACRE-FEET)
P.P. 6-4-52

FIGURE 5. Relation between first-day volume and total run-off in St. Louis Creek, 1948, 1949, and 1950.

Figure 15 from Report No. 2 is a combination of Figures 12 and 14, and shows directly the relation between height to the peak and total volume of run-off from one day's melt. That figure is paralleled in this report by Figures 7 and 8. Figure 7 shows the 1950 relation between height to the peak and total volume of run-off from one day's melt with the least squares line computed from 1948 and 1949 data drawn in. Figure 8 shows the same relationship using only days before and including the day of greatest volume in 1948, 1949, and 1950.

Figure 16 of Report No. 2 is replaced here by Figure 9 which shows the relationship of the height to trough and total run-off from one day's melt for the 1950 St. Louis Creek data. Superimposed on the plotting is the least squares line computed from the 1948 and 1949 data. Again this line seems to fit very well.

It is interesting to note that even though some of the computed volumes are negative, they still fit the same trend lines as the positive volumes.

FORECASTING RATES OF RUN-OFF FROM SNOWMELT

By means of snow measurements and their application to appropriately developed empirical relationships between water equivalent of the snow-pack on the watershed, other variables, and resulting stream flow, it is possible to make advance estimates of the volume of the seasonal run-off. For purposes of project development studies and mostly for use in the operation of water conservation projects, further refinement of the seasonal forecasts and estimates of the momentary seasonal peak discharge, as well as the daily stream flows, are needed as the run-off season progresses.

The purpose of this part of the investigation is to develop and test a method of forecasting the rates of run-off from snowmelt for 1950 by using observed meteorological data in the equations developed from the 1948 and 1949 data in Report No. 2. This method of forecasting rates of run-off from snowmelt makes use of the recession characteristics of stream flow from snowmelt discussed in the section on "Analysis of Rates of Snowmelt" both in this report and in Report No. 2 and of the area relationships shown in Figure 7 of Report No. 2.

1. Design Type of Forecast. Figure 10 shows three synthesized hydrographs superimposed on the actual observed hydrograph of St. Louis Creek (shown as solid line A) for the 1950 snowmelt season. The synthesized hydrographs were forecast by use of the 1950 meteorological data and the relationships derived from the combined 1948 and 1949 seasons. The dashed-line hydrograph B was synthesized as follows: Light's equation, Figure 11 in Report No. 2, was used with the basin coefficient K=0.956 as determined for days before and including the

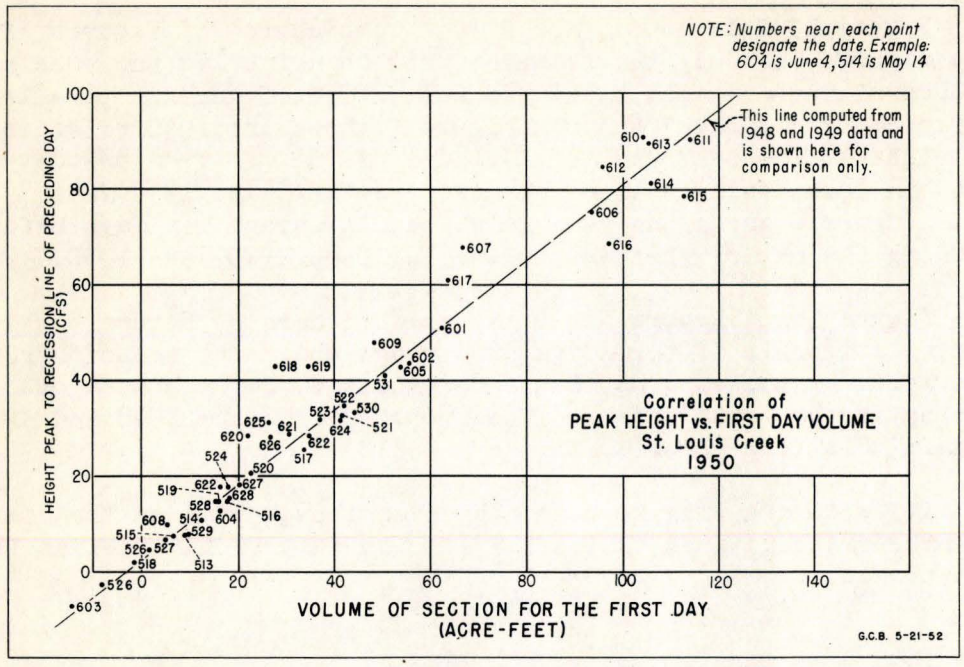

NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14
This line computed from 1948 and 1949 data and is shown here for comparison only.
Correlation of
PEAK HEIGHT vs. FIRST DAY VOLUME
St. Louis Creek
1950
HEIGHT PEAK TO RECESSION LINE OF PRECEDING DAY (CFS)
VOLUME OF SECTION FOR THE FIRST DAY (ACRE-FEET)
G.C.B. 5-21-52

FIGURE 6. Correlation of peak height to first-day volume, 1950.

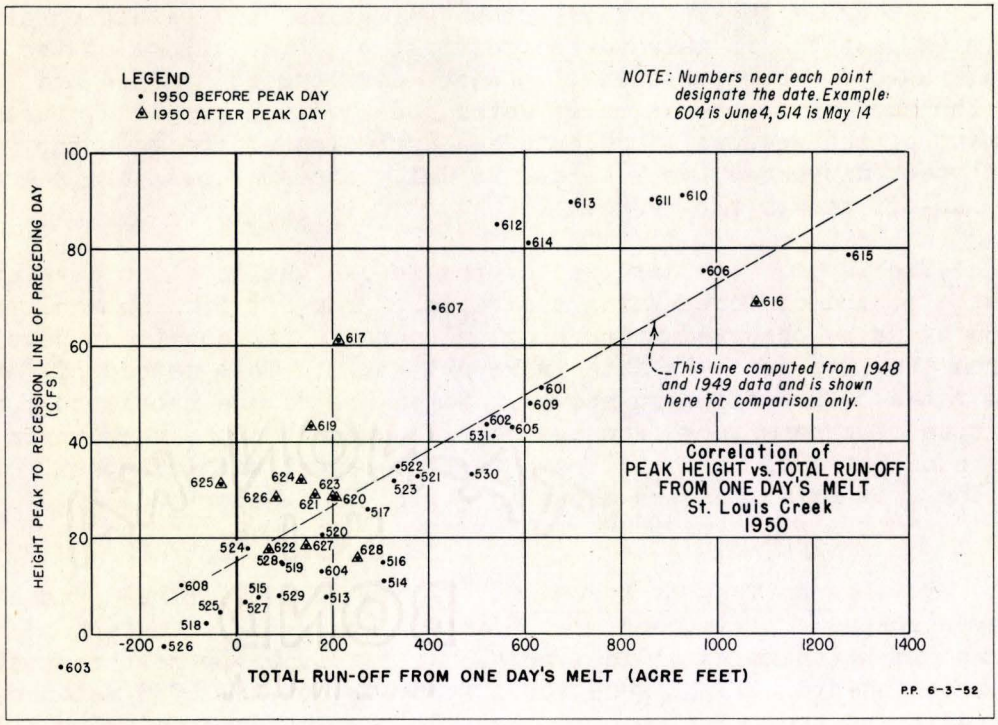

LEGEND
• 1950 BEFORE PEAK DAY
▲ 1950 AFTER PEAK DAY
NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14
This line computed from 1948 and 1949 data and is shown here for comparison only.
Correlation of
PEAK HEIGHT vs. TOTAL RUN-OFF
FROM ONE DAY'S MELT
St. Louis Creek
1950
HEIGHT PEAK TO RECESSION LINE OF PRECEDING DAY (CFS)
TOTAL RUN-OFF FROM ONE DAY'S MELT (ACRE FEET)
P.P. 6-3-52

FIGURE 7. Correlation of peak height to total run-off, 1950.

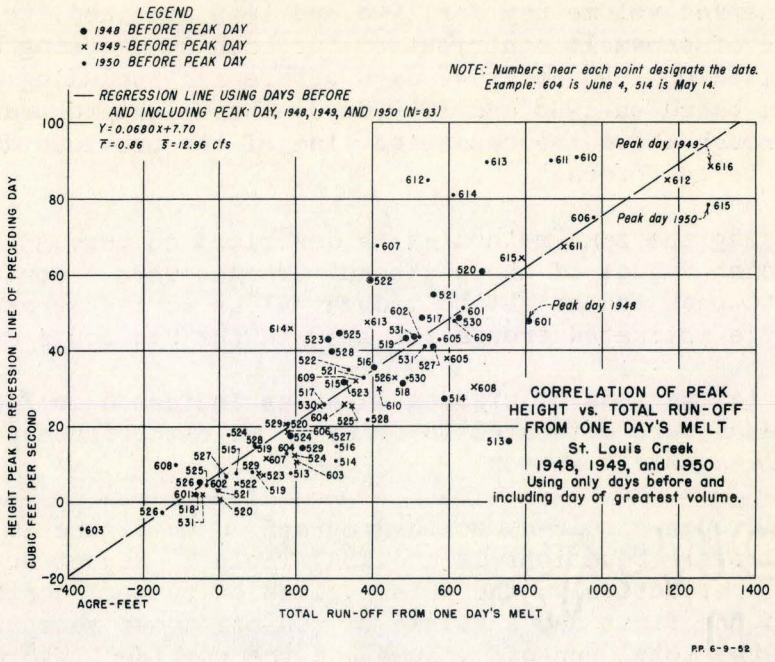

LEGEND
• 1948 BEFORE PEAK DAY
× 1949 BEFORE PEAK DAY
• 1950 BEFORE PEAK DAY
NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14.
REGRESSION LINE USING DAYS BEFORE AND INCLUDING PEAK DAY, 1948, 1949, AND 1950 (N=83)
Y=0.0680X+7.70
r=0.86 s=12.96 cfs
Peak day 1949
Peak day 1950
Peak day 1948
CORRELATION OF PEAK HEIGHT vs. TOTAL RUN-OFF FROM ONE DAY'S MELT
St. Louis Creek
1948, 1949, and 1950
Using only days before and including day of greatest volume.
HEIGHT PEAK TO RECESSION LINE OF PRECEDING DAY
CUBIC FEET PER SECOND
ACRE-FEET
TOTAL RUN-OFF FROM ONE DAY'S MELT
P.P. 6-9-52

FIGURE 8. Correlation of peak height to total run-off, 1948, 1949, and 1950.

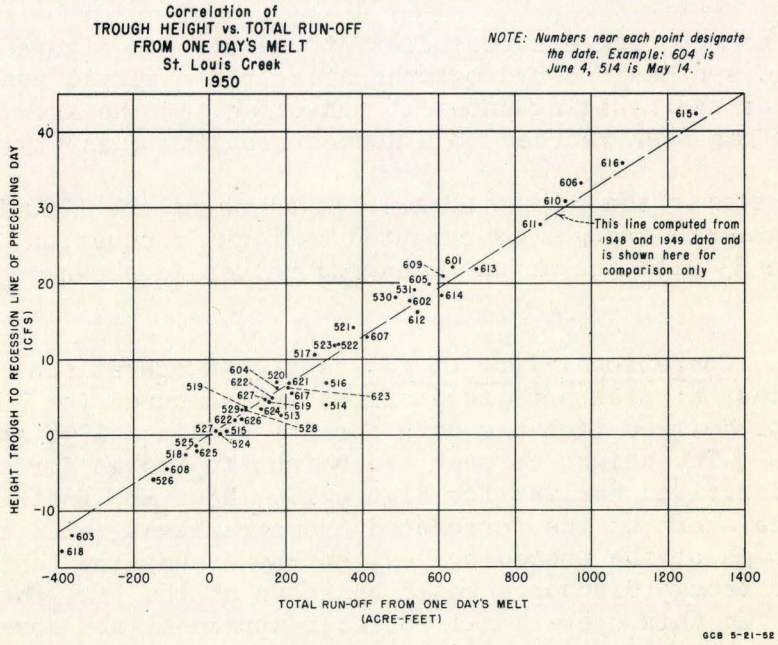

Correlation of
TROUGH HEIGHT vs. TOTAL RUN-OFF
FROM ONE DAY'S MELT
St. Louis Creek
1950
NOTE: Numbers near each point designate the date. Example: 604 is June 4, 514 is May 14.
This line computed from 1948 and 1949 data and is shown here for comparison only
HEIGHT TROUGH TO RECESSION LINE OF PRECEDING DAY (C.F.S.)
TOTAL RUN-OFF FROM ONE DAY'S MELT (ACRE-FEET)
GCB 5-21-52

FIGURE 9. Correlation of trough height to total run-off, 1950.

greatest observed volume day for 1948 and 1949 combined, to estimate the total volume of snowmelt contribution for each day. Using Figures 15 (equation based on 1948 and 1949 days before and including the peak) and 16 (equation based on 1948 and 1949 days) the height to peak and the height to trough above the recession line of the previous day were derived for the day being forecast.

Using the same method as is described on page 33 of Report No. 2 the point values of the peaks and troughs were computed by adding the height to peak and height to trough values to the recession from the previous day's estimated trough for 1950 in the St. Louis Creek basin.

Brief periods of missing data, as indicated on Figure 10, for the 1950 season were estimated in order to make the forecast continuous for the whole snowmelt season.

The open-circle-symbol hydrograph, C on Figure 10, was synthesized as follows: Equations 18 and 18A, Table 7, Report No. 2, were used to estimate, respectively, the total volume of run-off contribution for each day and the first day's volume of run-off above recession for each day. Using the total run-off volume and the combined 1948 and 1949 line in Figure 16 of Report No. 2, the height to trough for each day was estimated. The height to peak for each day was estimated using the first-day volumes and the 1948 and 1949 line in Figure 14 of Report No. 2. In similar manner as hydrograph B, hydrograph C was then synthesized using daily height to peak and height to trough values starting on May 13.

The barbed-wire-symbol hydrograph, D on Figure 10, was synthesized in the same manner from volumes estimated from Equations 33 and 33A, Table 7, Report No. 2.

The mounting discrepancies, to be seen on Figure 10 between observed and synthesized hydrographs after the observed peak, illustrate the danger of synthesizing snowmelt run-off after the snow remaining on a watershed has been reduced to a noncontributing quantity.

A comparison of the numerical values of the 1950 forecasted volumes, peaks and troughs as computed by Light's equation, Equation 18, and Equation 33 with the actual measured values is shown in Table 7.

2. Operational Type of Forecast. An operational type of day-by-day forecast of peak and trough flows was computed for 1950, using relationships derived from the data for the combined 1948 and 1949 snowmelt seasons. The height to peak and height to trough for each day were derived as described earlier for Figure 10. However, in this day-by-day forecast, the start of the forecasted hydrograph was taken to be the observed trough of the preceding day, on the assumption that the preceding day's trough discharge would be known at the time the forecast was being made. In this operational forecast approach, the more commonly available single indices such as degree-days and maximum temperatures were used.

COMPARISON OF RECORDED AND FORECASTED HYDROGRAPHS

1950 SNOWMELT SEASON

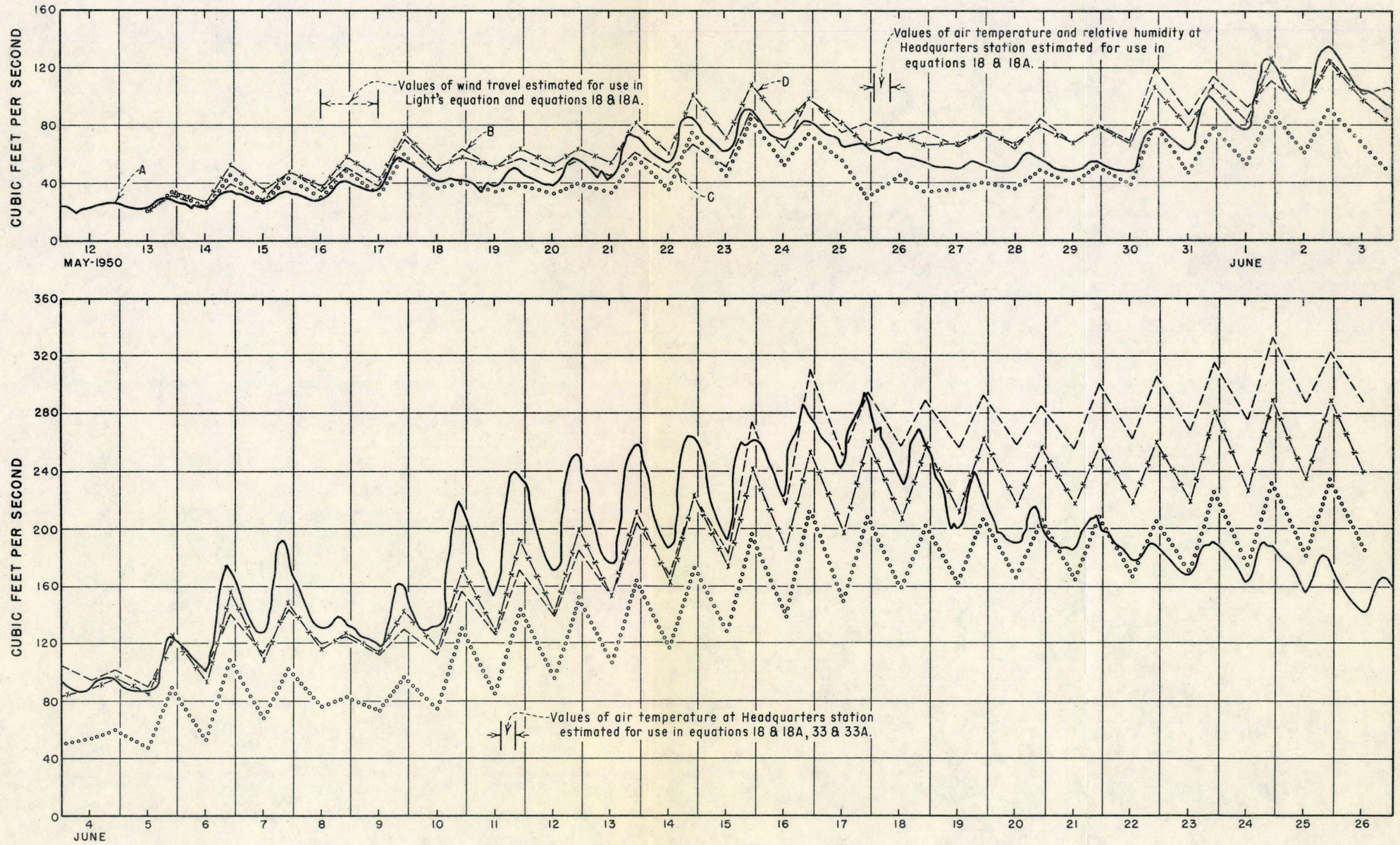
St. Louis Creek near Fraser, Colorado
Area - 32.8 square miles

A ——— Observed hydrograph from U.S.G.S. gaging station, St. Louis Creek

B – – – – – Hydrograph synthesized by using Light's equation with K = 0.956, as determined for days before peak for 1948 and 1949 combined.

C ooooooooo Hydrograph synthesized by using equations 18 and 18A, based upon combined data from 1948 and 1949.

D x—x—x—x Hydrograph synthesized by using equations 33 and 33A, based upon combined data from 1948 and 1949.



F.A.B
JULY 3, 1952

FIGURE 10

COMPARISON OF ESTIMATED VOLUMES, PEAKS, AND TROUGHS BASED ON USE OF LIGHT'S EQUATION

AND EQUATIONS 18, 18A, 33, and 33A FOR THE 1950 SEASON IN ST. LOUIS CREEK

Date	Measured from observed Hydrograph A *				Synthesized by Method B * using Light's Equation				Synthesized by Method C * using Equations 18 and 18A				Synthesized by Method D * using Equations 33 and 33A			
	Total volume	First day volume	Peak flow 1/	Trough flow 2/	Total volume 3/	First day volume 4/	Peak flow 1/ 11/	Trough flow 2/ 8/	Total volume 5/	First day volume 6/	Peak flow 1/ 7/	Trough flow 2/ 8/	Total volume 9/	First day volume 10/	Peak flow 1/ 7/	Trough flow 2/ 8/
	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
May 13	186	9	30	24	41	9	32	23	20	12	34	23	148	14	36	27
14	305	12	35	28	151	18	40	28	151	28	47	27	279	32	54	35
15	44	7	35	28	216	24	49	35	99	18	44	30	152	15	48	38
16	305	18	42	34	155a	19a	51a	37a	90	22	50	33	235	26	60	43
17	273	34	59	42	438a	42a	71a	49a	200a	34a	61a	37a	340	40	76	51
18	-62	-2	44	37	147	18	64	51	-1	3	41	35	101	8	59	51
19	95	15	51	38	12	7	57	48	7	4	39	33	159	16	65	53
20	179	23	58	42	15	7	55	45	82	7	40	33	141	13	64	54
21	377	42	74	54	159	19	61	47	193	31	59	37	315	36	84	61
22	337	42	87	62	219	24	67	51	349	51	79	46	449	54	104	71
23	329	37	92	70	517	49	89	65	343	49	86	54	420	51	112	81
24	22	18	86	65	475	45	100	76	157	26	75	56	224	24	99	82
25	-34	1	68	59	0	6	81	71	-211	-36	29	45	-124	-22	65	73
26	-150	-8	55	49	0	6	76	66	-199a	-17a	34a	36a	-22	-9	66	67
27	18	5	55	47	59	11	75	64	59	4	40	36	116	10	76	67
28	93	16	61	47	244	26	84	67	178	14	48	39	159	16	80	67
29	87	10	54	47	120	16	80	67	78	14	52	39	152	15	80	68
30	490	44	79	62	766	70	120	87	345	53	83	48	424	51	109	77
31	535	50	102	77	355	35	114	93	273	39	79	53	340	40	109	83
June 1	637	62	126	94	216	24	111	94	355	47	91	61	460	56	127	92
2	521	56	135	105	444	43	126	102	288	39	93	67	366	43	126	98
3	-366	-15	96	86	0	6	106	95	-266	-24	49	54	-98	-19	83	88
4	176	16	96	86	31	8	102	90	-77	7	60	48	116	10	96	86
5	574	54	126	100	498	47	126	100	289	53	91	54	424	51	127	94
6	976	93	172	126	607	56	142	113	560	72	111	69	663	83	159	109
7	411	67	191	131	443	43	144	119	387	43	103	76	442	53	151	116
8	-114	5	138	117	35	9	126	113	61	7	83	73	159	16	128	114
9	611	48	162	131	213	24	130	112	180	29	97	74	330	38	143	117
10	931	104	218	152	662	61	157	126	472	74	133	85	605	75	175	128
11	867	114	239	170	684	63	172	140	539a	77a	146a	96a	674a	85a	194a	142a
12	543	96	251	175	694	64	186	153	528	74	155	107	638	80	203	153
13	698	105	260	185	782	71	204	168	549	77	167	118	652	82	215	163
14	609	106	266	191	829	75	222	183	543	77	177	127	667	84	227	174
15	1,276	113	263	221	1,428	125	274	217	630	93	199	139	746	94	246	186
16	1,085	97	284	242	1,509	132	311	250	607	103	219	149	739	93	257	198
17	217	64	296	230	715	65	295	257	589	82	212	158	707	89	264	207
18	-391	27	269	200	518	49	289	256	451	61	204	162	580	72	260	212
19	155	34	239	191	594	55	293	258	468	63	209	167	576	72	265	216
20	208	22	215	185	439	42	286	255	296	54	207	165	456	55	256	217
21	164	30	209	178	755	69	302	262	419	60	210	167	496	61	261	218
22	68	16	191	168	713	65	306	268	402	53	207	169	500	61	263	220
23	204	35	191	162	774	70	315	275	519	81	231	175	696	88	285	227
24	133	41	191	155	967	86	334	287	568	80	235	181	703	89	293	235
25	-31	26	182	142	576	54	322	287	510	74	237	186	623	78	292	239

* Please refer to legend on Figure 10.

1/ Peak flow occurring at approximately 10 p.m. on date listed.

2/ Trough flow occurring at approximately noon of the next day.

3/ Total volume computed from Light's Equation using basin coefficient derived from 1948 and 1949 data using days before and including day of peak volume only.

4/ First day volume computed from Figure 12, Report No. 2, using days before and including day of peak volume only.

5/ Total volume computed from Equation 18 (Table 7, Report No. 2) which was derived from 1948 and 1949 data.

6/ First day volume computed from Equation 18A (Table 7, Report No. 2) which was derived from 1948 and 1949 data.

7/ Peak flow computed from Figure 14, Report No. 2.

8/ Trough flow computed from Figure 16, Report No. 2.

9/ Total volume computed from Equation 33 (Table 7, Report No. 2) which was derived from 1948 and 1949 data.

10/ First day volume computed from Equation 33A (Table 7, Report No. 2) which was derived from 1948 and 1949 data.

11/ Peak flow computed from Figure 15, Report No. 2, using line for days before and including day of peak volume only.

a Computed from estimated values of one or more of the weather elements.

TABLE 7. Comparison of estimated volumes, peaks, and troughs, 1950.

This operational forecast is shown in Figure 11. Line A is the actual hydrograph of the 1950 snowmelt season. Line E designates the daily peaks and troughs forecasted by using degree days above 32° F as computed from hourly temperatures from a thermograph trace. Line F shows the daily peaks and troughs forecasted by using the daily maximum temperature as read from the thermograph chart. The use of the daily maximum temperature makes it possible to forecast the peak rate of run-off which occurs on St. Louis Creek about 10:00 p.m. on the day of the observation, and the trough rate of run-off which occurs about noon on the following day.

SNOW DISAPPEARANCE STUDY.

During the 1950 snowmelt season (from April 1 to July 12) 13 periodic determinations at approximately 5- to 10-day intervals were made of the percent of the total drainage area that was covered with snow. Visual observations were made from three observation points from which practically all of the drainage area was visible on each of the dates, as well as a varying number of additional observation points. These visual observations were used to plot the snow-covered areas on an overlay map of the area from which planimeter measurements were made to derive the percent of snow cover. The snow-cover percentages determined by this method and their complements, the depletion of snow cover, are summarized in the following table:

Snow Cover Estimates

Date--1950	Snow Cover (Snow-covered area in percent of total drainage area)	Snow-cover depletion (Area without snow in percent of total drainage area)
April 1	97.7	2.3
4	100.0	0
14	94.9	5.1
27	93.5	6.5
May 9	91.7	8.3
12	89.2	10.8
19	90.0	10.0
June 6	70.1	29.9
13	49.2	50.8
20	36.3	63.7
27	18.7	81.3
July 3	7.2	92.8
12	2.1	97.9

The Snow Cover Depletion Curve is plotted on Figure 12. For comparison two additional curves are shown which represent the accumulation of stream flow. The Stream Flow Accumulation Curve shows the accumulated daily measured stream flow from April 1 expressed as a percent of the total April 1 to July 31 measured stream flow. Points on

COMPARISON OF ACTUAL AND DAY-BY-DAY FORECASTED HYDROGRAPHS

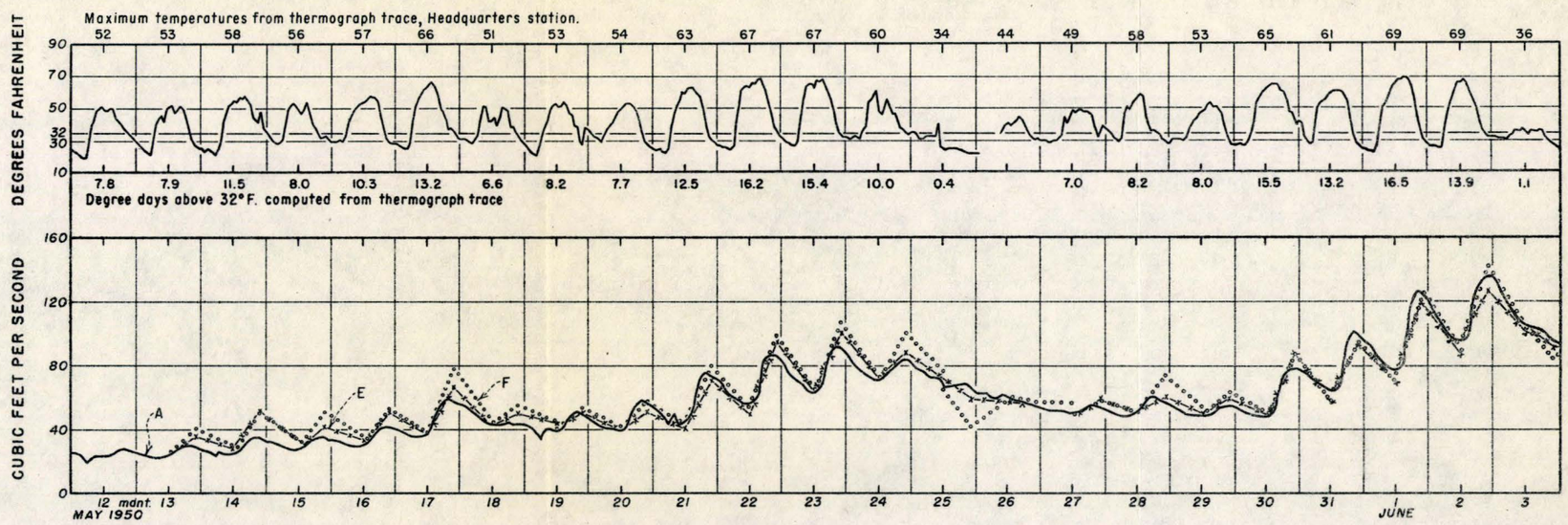
1950 SNOWMELT SEASON

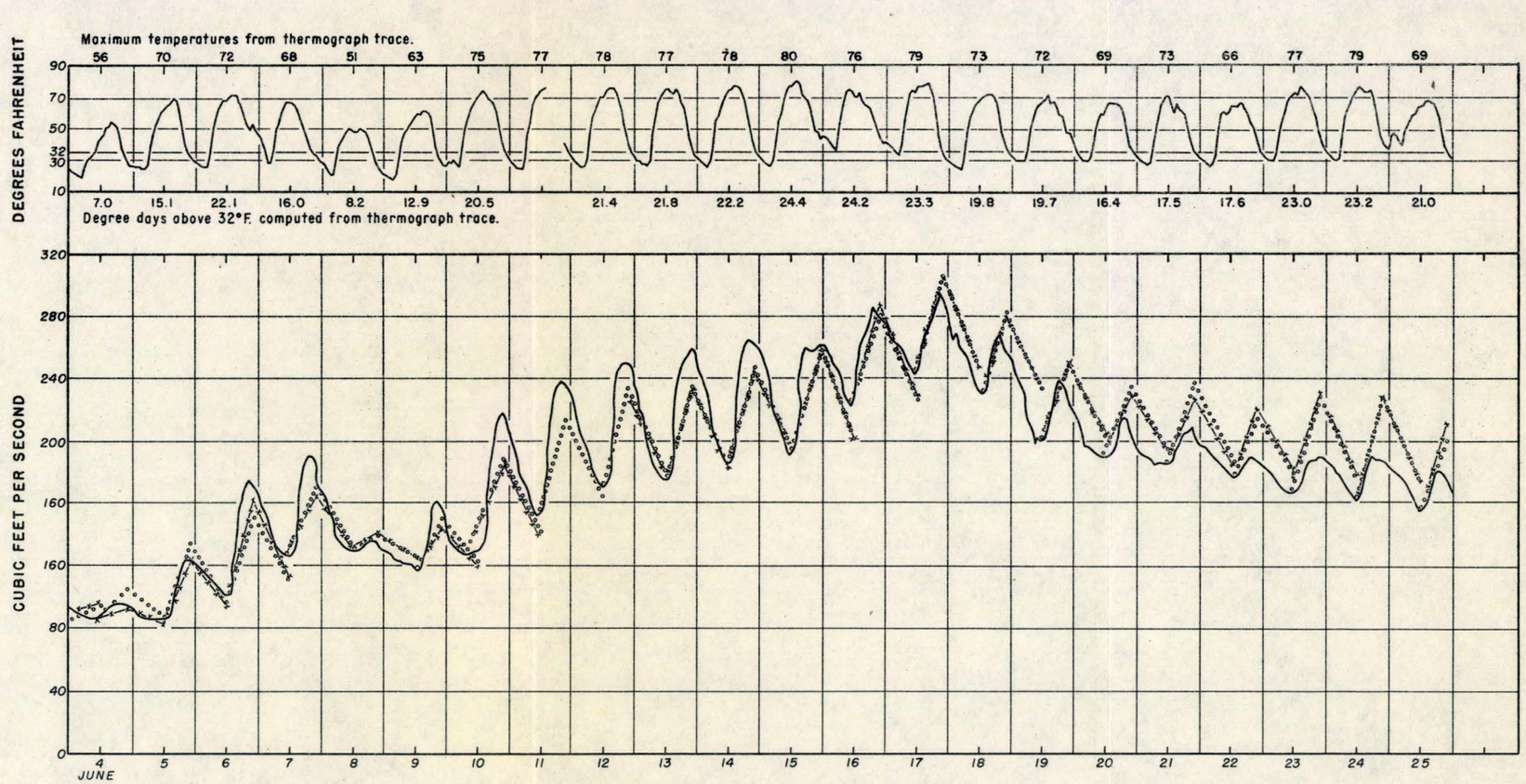
St. Louis Creek near Fraser, Colorado
Area - 32.8 square miles

A ——— Observed hydrograph from U.S.G.S. gaging station, St. Louis Creek

E ×—×—×—× Based upon degree days. Hydrograph synthesized by using equations 33 and 33A, based upon combined data from 1948 and 1949. Synthesis began daily at the observed trough flow.

F ••••••••• Based upon daily maximum temperature. Hydrograph synthesized by using equations 32 and 32A, based upon combined data from 1948 and 1949. Synthesis began daily at observed trough flow.





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JUNE 18, 1952

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EXPERIMENT STATION

FIGURE 11

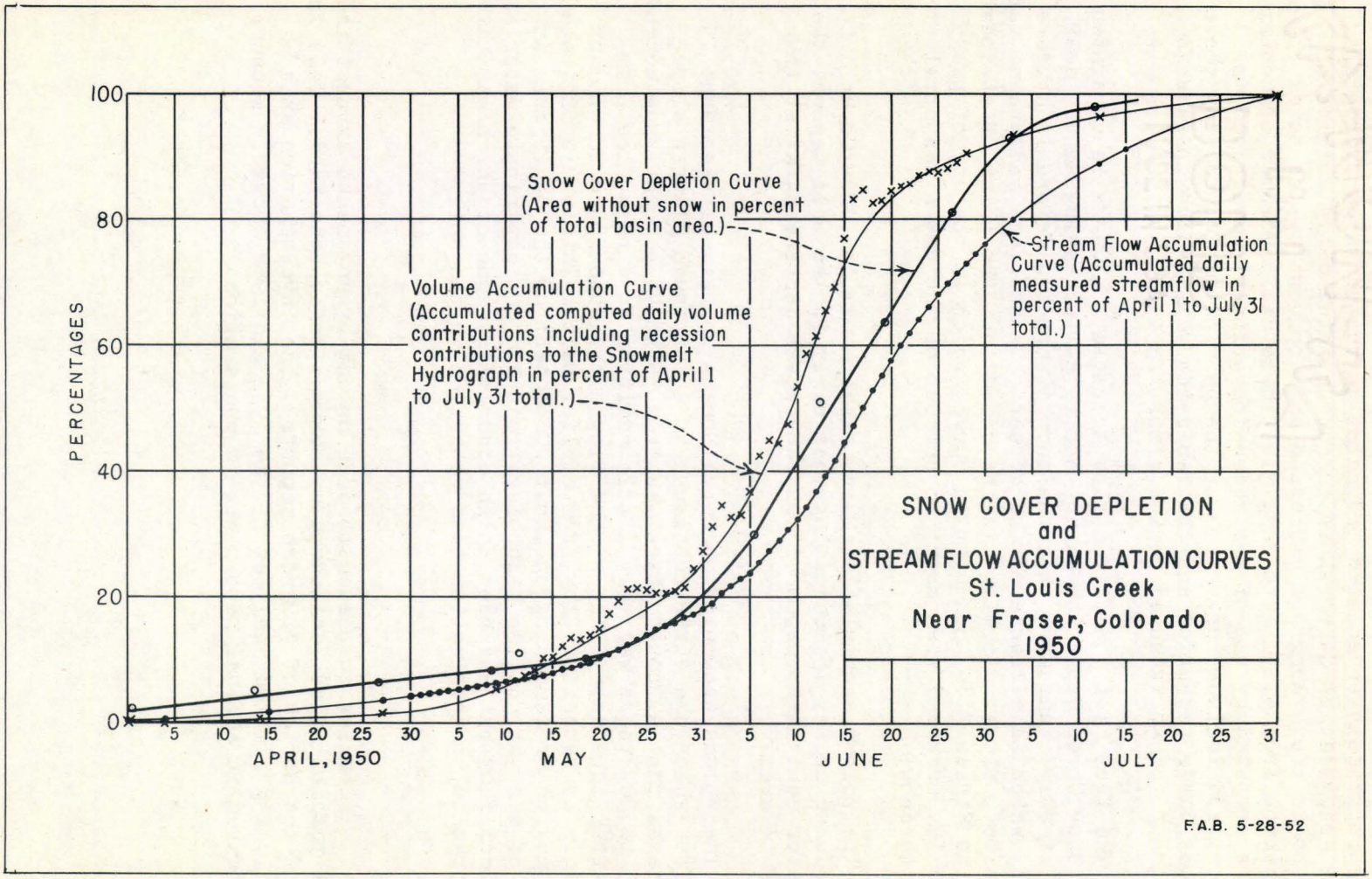

FIGURE 12. Snow cover depletion and stream flow accumulation curves.

this curve represent accumulated ordinates to the measured hydrograph. The Volume Accumulation Curve shows the accumulated daily volumes of contribution to the hydrograph expressed as a percent of the total volume of contribution from April 1 to July 31. These daily volumes of contribution were computed by use of the recession principle described in Report No. 1 and include the volume of the hydrograph for one day above the previous day's recession and the recession wedge which appears in the hydrograph for an extended period after the first day.

The fact that the Stream Flow Accumulation Curve is consistently below the Snow Cover Depletion Curve, and by an increasing amount near the first of July, indicates that the snow disappears before it appears as run-off, which is evidence of the effect of subsurface and ground-water, or "recession", flows. It will also be noted that the point of steepest slope to the Stream Flow Accumulation Curve, which is the day of peak flow, June 17, occurred when about 45 percent of the basin was still covered with snow.

The Volume Accumulation Curve rises above the Snow Cover Depletion Curve on May 15 indicating that early in the melt season, the average water equivalent depth of the snow cover decreases faster than the change in area.

The Volume Accumulation Curve breaks sharply between June 15 and 20, after which the curve continues at a very much flatter slope. This indicates that although there was from 35 to 45 percent snow cover on June 15 to 20, there was very little addition to stream flow from snowmelt after this date. The stream flow after June 15 to 20 was supported mainly by recession flow from earlier melt. This would indicate that the snow cover remaining on about 40 percent of the basin area at this time of the year at the high elevations did not contribute materially to the stream flow but was used up in other ways, some of which may have been evaporation, transpiration, and retention in the soil.

Studies completed to date do not by any means exhaust the analytical possibilities, and computations are being continued. This is the last of the series of progress reports. The investigation as a whole, including limited analyses of the 1951 and 1952 snowmelt seasons, will be treated in a final report now in preparation.

REFERENCES.

(1) BUREAU OF RECLAMATION-FOREST SERVICE COOPERATIVE SNOW INVESTIGATIONS. 1949. PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST, REPORT NO. 1, THE 1948 SNOWMELT SEASON. November, 65 pp. illus.

(2) BUREAU OF RECLAMATION-FOREST SERVICE COOPERATIVE SNOW INVESTIGATIONS. 1951. PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST, COLORADO, REPORT NO. 2, THE 1949 SNOWMELT SEASON. June, 88 pp. illus.

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